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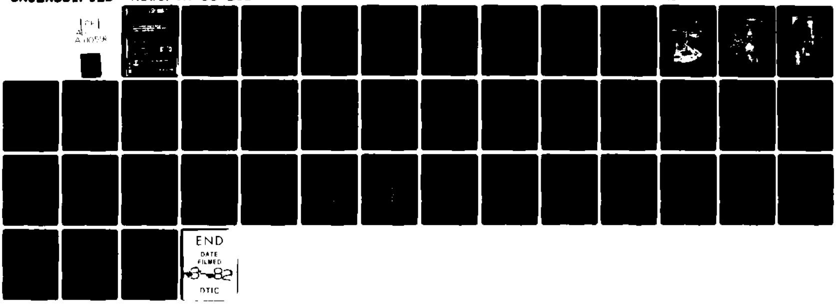

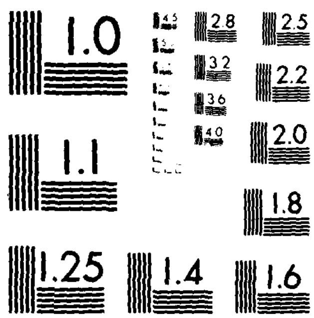
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The efficacy of aqueous foam for reducing the noise level due to the breech blast of a shoulder-launched rocket weapon was investigated experimentally. Results indicated that, for canisters of practical size, modest reductions in peak sound pressure level (SPL) could be achieved, at the expense of significantly increased recoil impulse.

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FOREWORD

This report was prepared as part of the Military Operations in Urban Terrain (MOUT) Program, a U.S. Marine Corps exploratory development effort under Naval Materiel Command Program Element 62332N ZF-32-300-082.

This report has been reviewed and approved by F. H. Maillie and J. F. Horton of the Systems Safety Division, Combat Systems Department.

Released by:

THOMAS A. CLARE, Head
Combat Systems Department

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INTRODUCTION

Considerable effort has been devoted recently toward reducing the noise signature of weapons, primarily to avoid hearing damage to nearby personnel. One type of weapon that has received a great deal of attention is the shoulder-launched in-tube-burning rocket. The need for reduced noise level becomes more acute when the weapon is to be fired from an enclosed space such as might occur in urban warfare.

Recent investigations[1,2,3] have shown that aqueous foam can greatly reduce the blast pressure resulting from explosive charge detonations and gun muzzle blast. The aqueous foam that has been used for this purpose is basically foam of the type commonly used in firefighting. In the case of guns, the foam was contained in a metal canister mounted on the gun muzzle, and resulted in peak sound pressure level (SPL) reductions in excess of 20 dB.[3] Since the propellant gas flow from the muzzle of a gun bears some resemblance to that from the breech of a shoulder-fired rocket launcher, it seemed plausible that a foam-filled canister mounted on the breech of such a launcher tube might yield significant noise level reductions.

OBJECTIVE

The objective of the investigation reported herein was to determine the feasibility and efficacy of aqueous foam for reduction of noise due to the firing of a shoulder-launched rocket weapon.

APPARATUS

The rocket launcher used for the experiments was the 66-mm M72A2 Light Antitank Weapon (LAW), chosen as being representative of the weapon type and because of availability. The LAW round was mounted in the cradle of a ballistic pendulum as shown in Figure 1 and was fired by means of a yoke linkage actuated by an automotive solenoid. The warhead was detonated against a large steel plate located approximately 100 meters downrange. The ballistic pendulum enabled measurement of recoil impulse* as described in detail in Appendix A. Each component used for each test round was carefully weighed; extra weight was added for some rounds, for which large recoil impulse was expected, to maintain the motion of the pendulum within safe limits. The motion of the pendulum was measured by means of a pen attached to one of the suspension rods in such a fashion that it traced an arc on an indicator card, enabling measurement of the maximum angular motion of the pendulum.

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*Here "impulse" has the strict meaning "time integral of force."

Instrumentation consisted of four blast gages and a wall pressure gage, as described in detail in Table B-1 of Appendix B. The gages are shown in the photographs of Figures 1, 2, and 3. A General Radio Model 1982 sound level meter, located at 200 ft (61 meters) from the breech along an azimuth 130° from the line of fire, was used to document the far-field SPL. All data was recorded on magnetic tape using an FM recorder with 40 kHz frequency response.

The aqueous foam used was firefighting foam produced at an expansion ratio of 27. Each test round that utilized foam was fired within 3 minutes after the foam was produced, to minimize changes in foam characteristics due to foam structure deterioration. The foam was contained in aluminum canisters described in detail in Reference 4; a typical canister is shown in Figure 3. Shapes and sizes of the canisters tested are described in detail in Appendix B.

RESULTS

Typical raw data plots are shown in Appendix C. Tabulated numerical data and calculated performance parameters are shown in Appendix B. Table B-3, a compilation of data from bare breech rounds only, illustrates clearly that considerable round-to-round variation in noise level (standard deviation of about one to two decibels) occurred. This variability must be kept in mind during interpretation of the data.

The effects of the empty canisters, relative to bare breech, are summarized in Table B-5. It can be seen that the empty canister configurations tested offer a generally modest (~5 dB) reduction in peak noise level at the gunner's head location, at the expense of a significant (~3 lbf-sec) increase in recoil impulse.*

The data showing the effect of the foam, relative to the empty canisters, are summarized in Table B-6. These data indicate that the peak noise level reduction due to foam is apparently not large, perhaps on the order of two decibels. The data, unfortunately, demonstrates considerable variability. Also, the LAW uses "det cord" as the ignition link between a percussion cap and the rocket motor, which results in a shock wave prior to rocket motor ignition. Evidence of the det cord noise may be seen in the far-field noise data of Figure C-3, which is peak flat (unweighted) sound pressure level "peak-and-hold" data. In Figure C-3(a) the initial level is the maximum ambient level (about 97 dB) prior to the test round. The first level change is due to the det cord, followed several milliseconds later by a larger level change due to the breech blast. This same sequence is present in Figure C-3(b), with the

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*A recoil impulse of 3 lbf-sec is roughly characteristic of typical shotguns and high-powered sporting rifles.

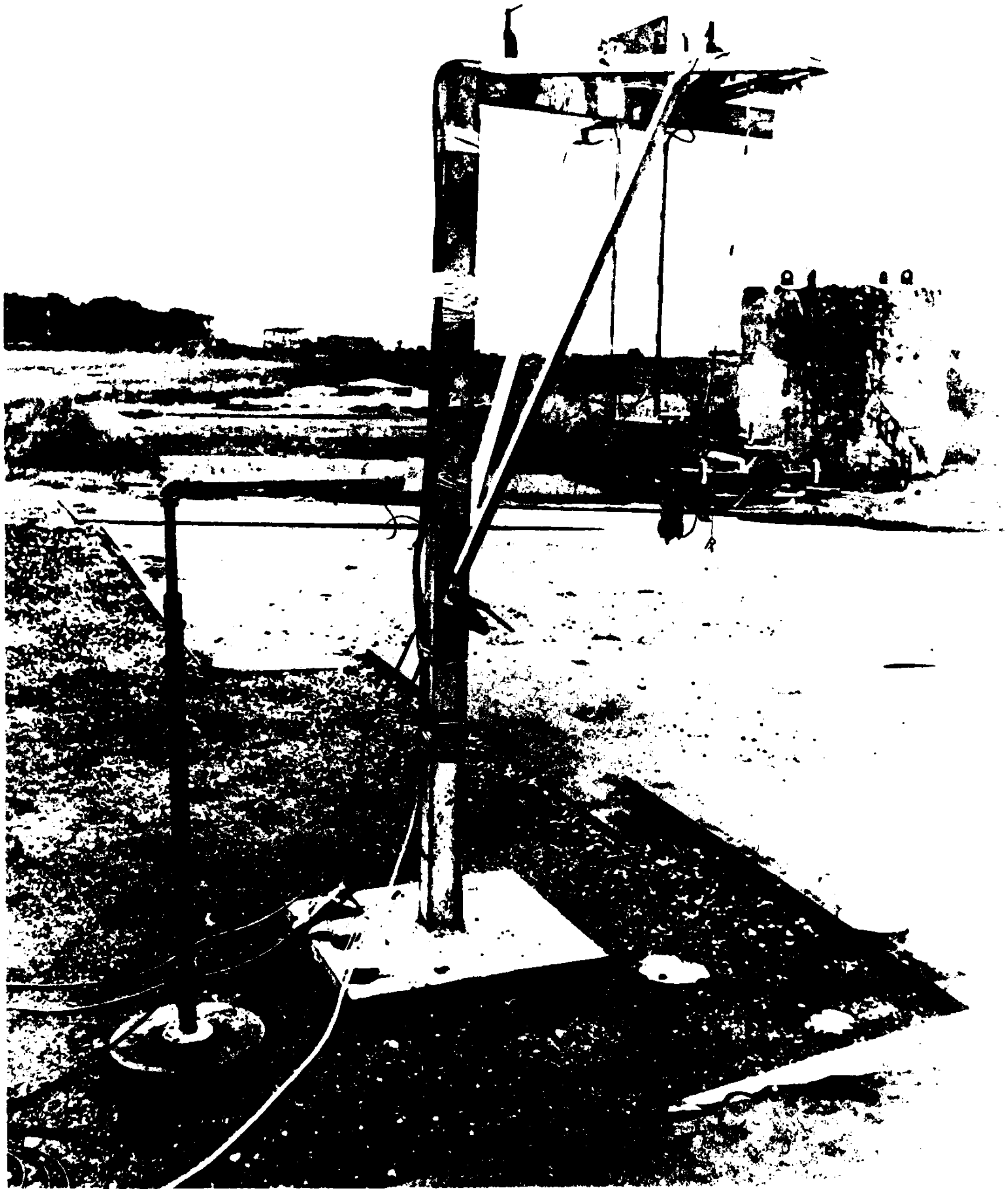

Figure 1. Ballistic Pendulum With LAW Installed in Cradle

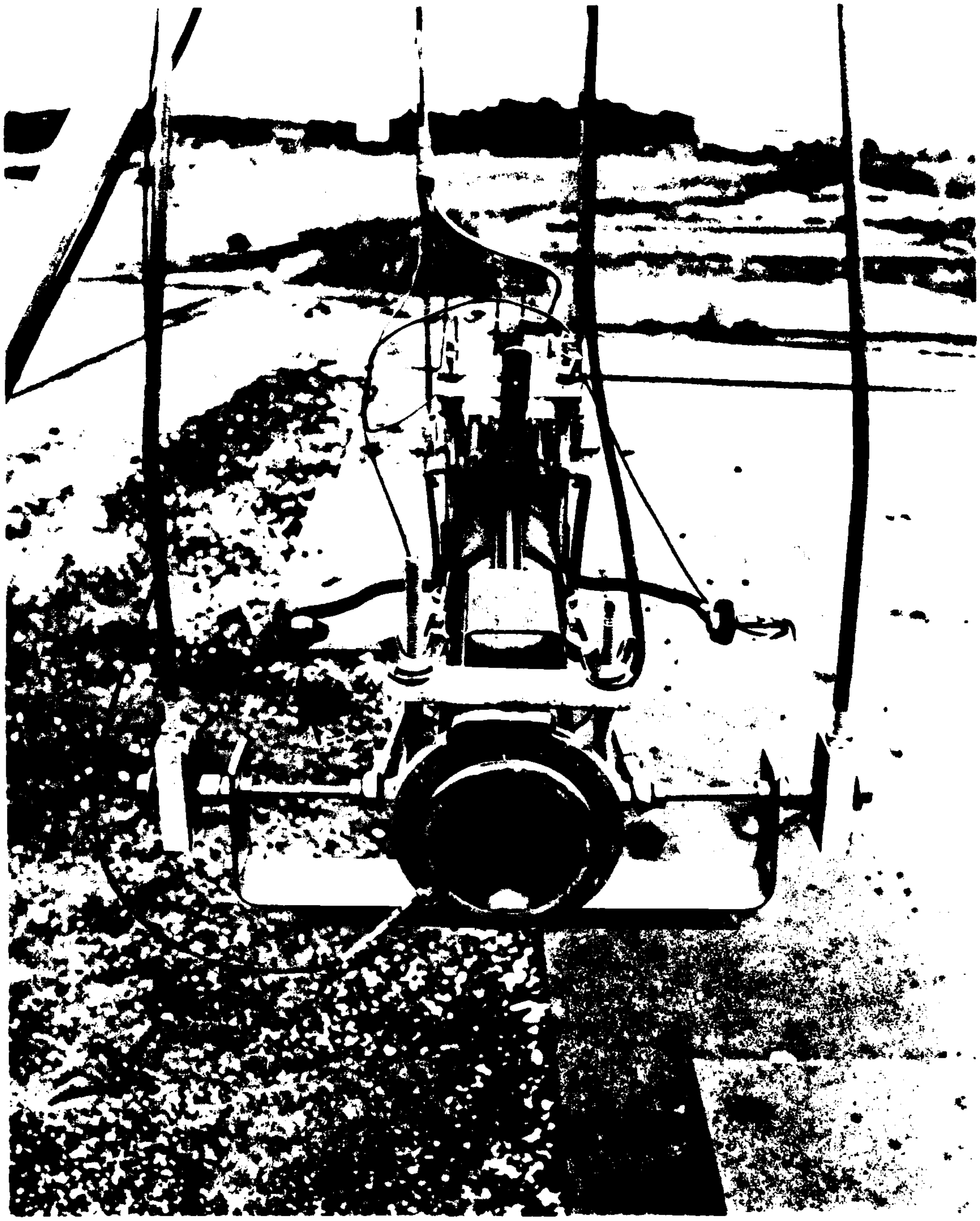

Figure 2. Breech View of Pendulum and Near-Field Pressure Transducers (LAW Installed in Cradle)

det cord noise level evidently somewhat reduced by the empty canister. Figure C-3(c) shows that the foam reduced the det cord noise to a level lower than the initial maximum ambient level. The above description applies to all of the data rounds. It is possible that the shock wave due to the det cord may have dispersed or otherwise affected the foam such that only a small reduction in breech blast noise level was obtained. Thus, the effect on shoulder-launched rocket noise level due to a foam-filled canister was not conclusively demonstrated in the present experiment. It is clear from the data presented in Table B-6 that filling the canisters with foam resulted in greatly increased recoil impulse.

CONCLUSIONS

Aqueous foam contained in breech-mounted metal canisters yielded rather small peak noise level reductions, at the expense of greatly increased recoil impulse. Size, weight, and remaining engineering development of suitable canisters and foam generators are other important considerations. Thus, it appears doubtful that aqueous foam will be of general utility for reducing noise levels due to shoulder-launched rocket weapons.

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2. D. Dadley, E. Robinson, and V. Pickett, *The Use of Foam to Muffle Blasts from Explosions*, paper presented at IEP-ABCA-5 conference at Indian Head, MD, June 1976.

3. Pater, L. L. and J. W. Shea, *Use of Foam to Reduce Gun Blast Noise Levels*, NSWC TR 81-94, Naval Surface Weapons Center, Dahlgren, VA, March 1981.

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APPENDIX A

BALLISTIC PENDULUM

BALLISTIC PENDULUM

Consider a ballistic pendulum as shown in Figure A-1, consisting of a mass m_p suspended by N rods each of mass m_i ($i = 1, 2, \ldots, N$) and uniform length ℓ. The mass m_p is acted upon by an impulsive horizontal force $F_R(t)$, which is of such short duration Δt that very little motion occurs* ($\Theta \simeq 0$).

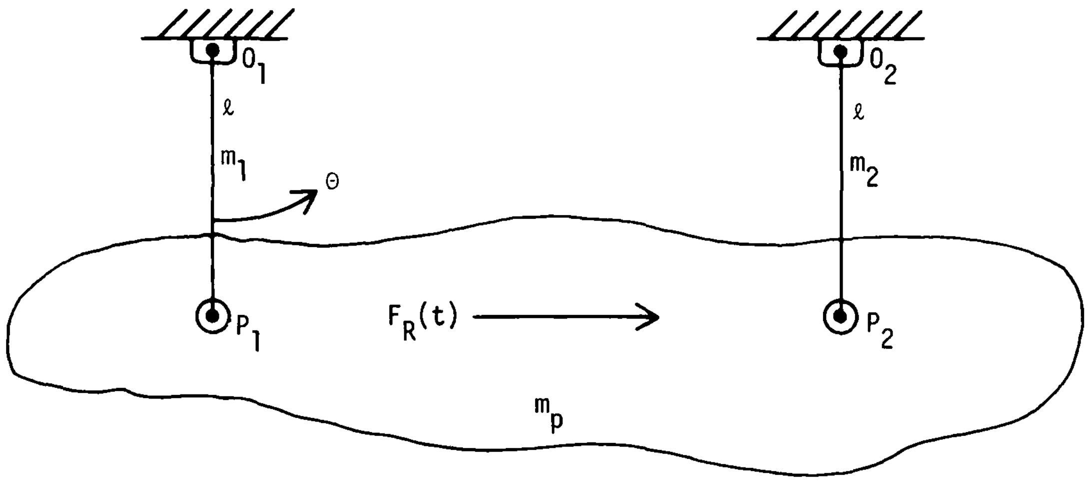

Figure A-1. Ballistic Pendulum

Consider a typical rod, as shown in Figure A-2. Making use of the principle that angular impulse is equal to the change in angular momentum, with rotation about the fixed point O_i, leads to the expression

$$\ell \int_{\Delta t} F_{i_x} \, dt = I_{o_i} w = \frac{m_i \ell^2}{3} \frac{V_p}{\ell} \tag{A-1}$$

or

$$\int_{\Delta t} F_{i_x} \, dt = \frac{m_i V_p}{3}$$

where V_p is the magnitude of the (essentially horizontal) velocity of the pendulum mass after the short time Δt.

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*The period of oscillation of the experimental apparatus was approximately two seconds, whereas the duration of the recoil force due to the rocket motor was about two milliseconds. Thus, the impulsive-force model is appropriate.

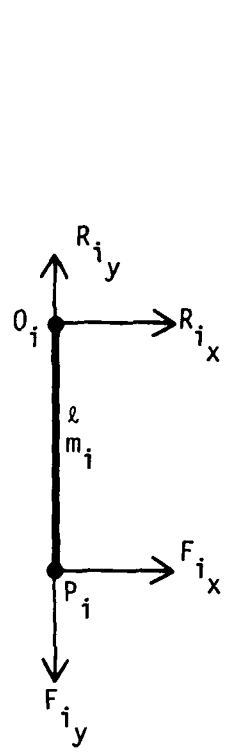

Figure A-2. Free Body Diagram of a Typical Rod

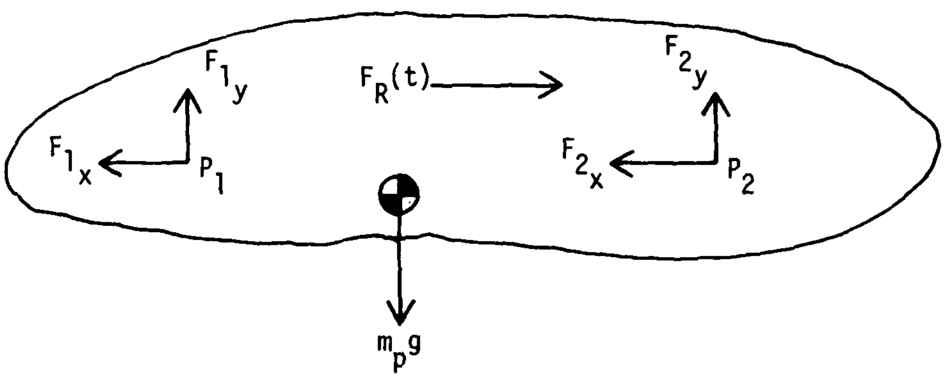

Figure A-3. Free Body Diagram of Pendulum Mass (showing two typical suspension points)

Now consider the pendulum mass. Making use of the fact that linear impulse is equal to the change in linear momentum yields

$$\int_{\Delta t} F_R dt - \sum_{i=1}^{N} \int_{\Delta t} F_{i_x} dt = m_p V_p \tag{A-2}$$

Using equation A-1 to eliminate the terms involving the internal components, F_{i_x} yields

$$I_R = \int_{\Delta t} F_R(t) dt = m_p V_p + \sum_{i=1}^{N} \frac{m_i V_p}{3}$$

or

$$I_R = V_p \left(m_p + \frac{1}{3} \sum_{i=1}^{N} m_i \right) \tag{A-3}$$

Energy methods can be used to determine how high the pendulum swings. Note that the center of mass of the uniform suspension rods rises half as much as the pendulum mass.

$$\sum_{i=1}^{N} \frac{1}{2} I_{o_i} w^2 + \frac{1}{2} m_p V_p^2 = m_p gh + \sum_{i=1}^{N} m_i g \frac{h}{2}$$

But

$$I_{o_i} = \frac{m_i \ell^2}{3} \quad \text{(for a uniform slender rod)}$$

$$w = V_p / \ell$$

so

$$\frac{V_p^2}{2} \left(m_p + \frac{1}{3} \sum_{i=1}^{N} m_i \right) = gh \left(m_p + \frac{1}{2} \sum_{i=1}^{N} m_i \right) \tag{A-4}$$

where

$$h = \ell(1 - \cos \Theta) \tag{A-5}$$

Combining equations A-3 and A-4 to eliminate V_p yields*

$$I_R^2 = 2gh\left(m_p + \frac{1}{3}\sum_{i=1}^{N} m_i\right)\left(m_p + \frac{1}{2}\sum_{i=1}^{N} m_i\right) \qquad \text{(A-6)}$$

A graphical representation of equation A-6 is shown in Figure A-4. These curves were used during the experiment to select appropriate values of pendulum mass m_p to maintain pendulum rise h within safe limits.

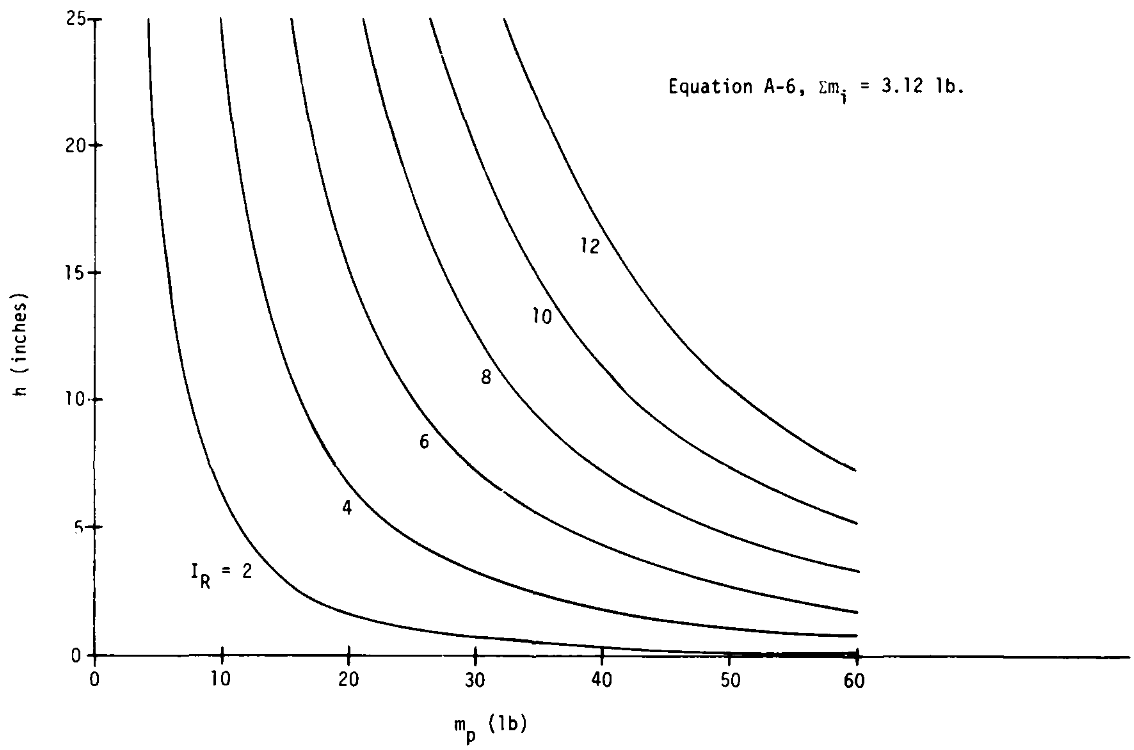

Figure A-4. Ballistic Pendulum Parameters

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*Note that if the mass of the rods is neglected, the result becomes

$$I_R^2 = 2gh\, m_p^2$$

which is the result for a simple pendulum.

APPENDIX B

EXPERIMENTAL DATA

CANISTER CONFIGURATION NOMENCLATURE

Test rounds that did not employ any canister, fired to provide baseline information, are denoted by "BB" (Bare Breech). The various canister configurations tested are denoted by a shorthand notation as follows:

C - D - L - __________

- Additional information, as required, e.g., "OPEN" to indicate open aft end, or numbers to indicate internal baffle locations (inches aft of breech exit plane)
- L: Canister inside length (inches)
- D: Canister inside diameter (inches)
- C: "C" indicates "empty canister;" "F" indicates "foam-filled canister."

For example, F-8-9-3,6 would signify a foam-filled canister of 8" I.D., 9" in length, with interior baffles at 3" and at 6" behind the launch tube exit plane. The configuration C-10 consisted of simply a 10 inch (25.4 cm) diameter disk attached to the breech of the launcher. All baffles and endcaps utilized a 2.6 inch (66 mm) diameter center hole, which is the same as the inside diameter of the launch tube.

Table B-1. Transducer Types and Locations

Symbol	Transducer	Location
P1	PCB 113A51 "Lollipop"	P1 and P2 were located approximately 90 cm (35.5 in.) from the breech exit plane centroid (for bare breech rounds) or the canister exit plane centroid, along an azimuth of 90° from the direction of fire.
P2	Susquehanna ST-2	
P3	Susquehanna ST-2	12.3 cm (4.8 in.) left of tube centerline, 21.5 cm (8.5 in.) forward of launch tube exit plane (represents [illegible]'s head location), transducer oriented with plane of sensing surface through launch tube centerline (see Figure 2).
P4	Susquehanna ST-2	12.3 cm (4.8 in.) right of tube centerline, 21.5 cm (8.5 in.) forward of launch tube exit plane (reflection of P3 location), transducer oriented with plane of sensing surface vertical and parallel to launch tube centerline (see Figure 2).
P5	PCB 111A22	Located in the breech support ring of the ballistic pendulum apparatus, used to provide zero reference for elapsed time for the other pressure gages.

Table B-2. Near Field Peak Overpressure Data

Round No.	Configuration	Peak Overpressure (psi) @			
		P1	P2	P3	P4
1	BB	1.70	1.90	2.23	--
2	BB	2.50	2.40	2.52	--
3	BB	2.55	2.50	2.26	1.60
4	C-8-3	2.60	2.25	1.20	0.82
5	F-8-3	2.05	1.25	1.10	1.08
6	C-10-3	3.00	2.35	0.92	1.18
7	F-10-3	1.50	1.40	0.98	1.24
8	F-10-3	1.60	1.35	1.74	2.00
9	C-8-9	1.70	1.58	0.80	0.90
10	BB	2.21	2.05	1.58	2.18
11	BB	2.72	--	2.40	2.70
12*	F-8-9	*	*	*	*
13	C-8-9-Open	2.82	2.32	2.43	2.04
14**	F-8-9-Open	1.90	1.93	2.08	1.52
15	BB	2.52	2.20	2.16	2.68
16	C-8-6	2.37	1.78	1.18	1.34
17	F-8-6	1.62	1.33	1.10	0.52
18*	C-10-6	*	*	*	*
19	BB	2.65	--	2.41	2.32
20	C-8-6-3	2.63	1.92	1.08	1.12
21	F-8-6-3	1.25	1.10	0.9	0.79
22	C-8-9-3,6	1.85	1.40	1.01	0.89
23	F-8-9-3,6	1.40	--	0.82	0.83
24	C-10	2.08	2.10	1.28	1.39
25	BB	2.31	--	1.70	1.78
26	C-8-9-3,6	2.00	1.90	0.80	0.98
27	C-10-6-3	2.31	--	1.18	1.57

* Data invalid due to hardware malfunction.

** Most of the foam ran out of the open aft end of the canister before the round could be fired.

Table B-3. Bare Breech Overpressure Data

Round No.	P1 (psi)	P2 (psi)	P3 (psi)	P4 (psi)
1	1.70	1.90	2.23	--
2	2.50	2.40	2.52	--
3	2.55	2.50	2.26	1.60
10	2.21	2.05	1.58	2.18
11	2.72	--	2.40	2.70
15	2.52	2.20	2.16	2.68
19	2.65	--	2.41	2.32
25	2.31	--	1.70	1.78
Mean	2.40 (178.4 dB)	2.21 (177.6 dB)	2.16 (177.4 dB)	2.21 (177.6 dB)
σ	0.33	0.24	0.34	0.45
	P1 (dB)	P2 (dB)	P3 (dB)	P4 (dB)
1	175.4	176.3	177.7	--
2	178.7	178.4	178.8	--
3	178.9	178.7	177.8	174.8
10	177.6	177.0	174.7	177.5
11	179.4	--	178.4	179.4
15	178.8	177.6	177.4	179.3
19	179.2	--	178.4	178.1
25	178.0	--	175.4	175.8
Mean	178.2	177.6	177.3	177.5
σ	1.3	1.0	1.5	1.9

Table B-4. Ballistic Pendulum Recoil Impulse Data

Round No.	Configuration	m_p (lbm)	2Θ (deg)	h (in.)	I_R (lbf-sec)
1	BB	15.86	5.5	0.04	0.25
2	BB	15.84	4.5	0.03	0.21
3	BB	15.80	3.5	0.02	0.17
4	C-8-3	24.98	23.4	0.74	1.63
5	F-8-3	25.18	59.3	4.68	4.12
6	C-10-3	28.74	20.6	0.58	1.65
7	F-10-3	29.09	72.0	6.82	5.71
8	F-10-3	29.42	84.0	9.17	6.70
9	C-8-9	30.46	62.5	5.18	5.20
10	BB	16.16	--	--	--
11	BB	16.41	8.0	0.09	0.38
12*	F-8-9	54.25	*	*	*
13	C-8-9-Open	26.64	26.5	0.95	1.96
14	F-8-9-Open	26.71	21.0	0.60	1.56
15	BB	16.51	7.0	0.07	0.34
16	C-8-6	51.00	29.5	1.18	4.09
17	F-8-6	51.40	61.5	5.02	8.50
18*	C-10-6	55.48	*	*	*
19	BB	16.43	7.5	0.08	0.36
20	C-8-6-3	29.84	39.0	2.05	3.21
21	F-8-6-3	43.13	65.0	5.59	7.56
22	C-8-9-3,6	46.99	30.5	1.27	3.92
23	F-8-9-3,6	47.63	83.0	8.97	10.55
24	C-10	20.01	12.5	0.21	0.70
25	BB	29.35	--	--	--
26	C-8-9-3,6	47.00	32.0	1.38	4.08
27	C-10-6-3	48.02	22.0	0.66	2.88
1,2,3,11,15,19	BB (Mean)	--	--	--	0.28

* Data invalid due to hardware malfunction.

NOTE: ℓ = 35.72 inches (90.7 cm) and Σm_i = 3.12 lbm (1.4 kg) for all rounds. Weight was added to m_p for some rounds to maintain Θ within safe limits.

Table B-5. Effect of Empty Canisters Relative to Bare Breech

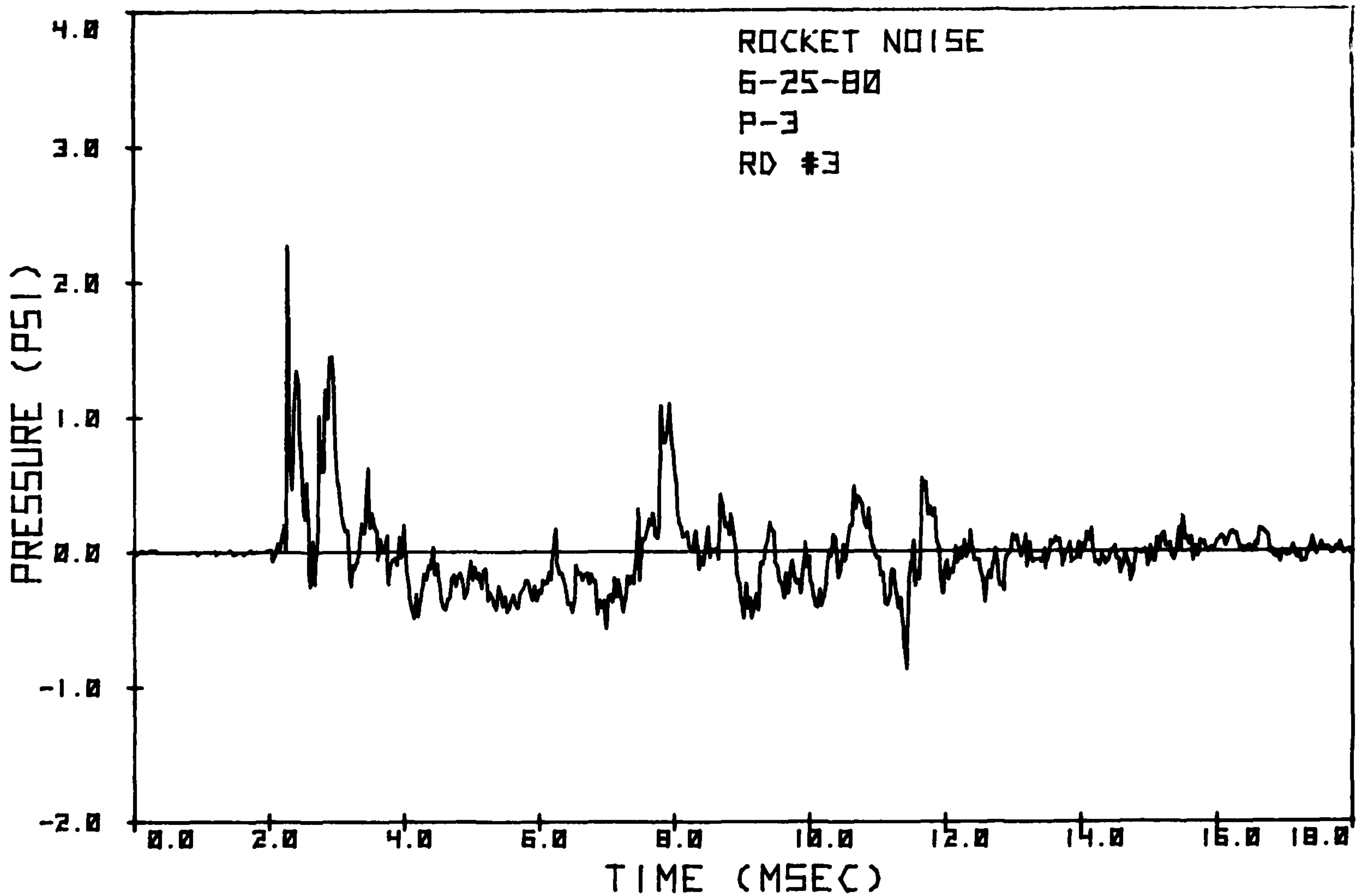
Configuration	Round No.	I_R (lbf-sec)	ΔI_R (lbf-sec)	P1 (dB)	ΔP1 (dB)	P2 (dB)	ΔP2 (dB)	P3 (dB)	ΔP3 (dB)	P4 (dB)	ΔP4 (dB)
BB (Mean) "Baseline"	1,2,3, 11,15,19	0.28	--	178.2	--	177.6	--	177.3	--	177.5	--
C-8-3	4	1.63	+1.35	179.0	+0.8	177.8	+0.2	172.3	-5.0	169.0	-8.5
C-8-6	16	4.09	+3.81	178.2	+0.0	175.8	-1.8	172.2	-5.1	173.3	-4.2
C-8-6-3	20	3.21	+2.93	179.2	+1.0	176.4	-1.2	171.4	-5.9	171.7	-5.8
C-8-9	9	5.20	+4.92	175.4	-2.8	174.7	-2.9	168.8	-8.5	169.8	-7.7
C-8-9-Open	13	1.96	+1.68	179.8	+1.6	178.1	+0.5	178.5	+1.2	176.9	-0.6
C-8-9-3,6	22	3.92	+3.64	176.1	-2.1	173.7	-3.9	170.8	-6.5	169.7	-7.8
C-8-9-3,6	26	4.08	+3.80	176.8	-1.4	176.3	-1.3	168.8	-8.5	170.6	-6.9
C-10 (Disk)	24	0.70	+0.42	177.1	-1.1	177.2	-0.4	172.9	-4.4	173.6	-3.9
C-10-3	6	1.65	+1.37	180.3	+2.1	178.2	+0.6	170.0	-7.3	172.2	-5.3
C-10-6-3	27	2.88	+2.60	178.0	-0.2	--	--	172.2	-5.1	174.7	-2.8

Table B-6. Effect of Foam Relative to Empty Canisters

Configuration	Round No.	I_R (lbf-sec)	ΔI_R (lbf-sec)	P1 (dB)	ΔP1 (dB)	P2 (dB)	ΔP2 (dB)	P3 (dB)	ΔP3 (dB)	P4 (dB)	ΔP4 (dB)
F-8-3	5	4.12	+2.49	177.0	-2.0	172.7	-5.1	171.6	-0.7	171.4	+2.4
F-8-6	17	8.50	+4.41	174.9	-3.3	173.2	-2.6	171.6	-0.6	165.1	-8.2
F-8-6-3	21	7.56	+4.35	172.7	-6.5	171.6	-4.8	169.8	-1.6	168.7	-3.0
F-8-9-3,6	23	10.55	+6.63	173.7	-2.4	--	--	169.0	-1.8	169.1	-0.6
F-10-3	7	5.71	+4.06	174.3	-6.0	173.7	-4.5	170.6	+0.6	172.6	+0.4
F-10-3	8	6.70	+5.05	174.8	-5.5	173.3	-4.9	175.6	+5.6	176.8	+4.6

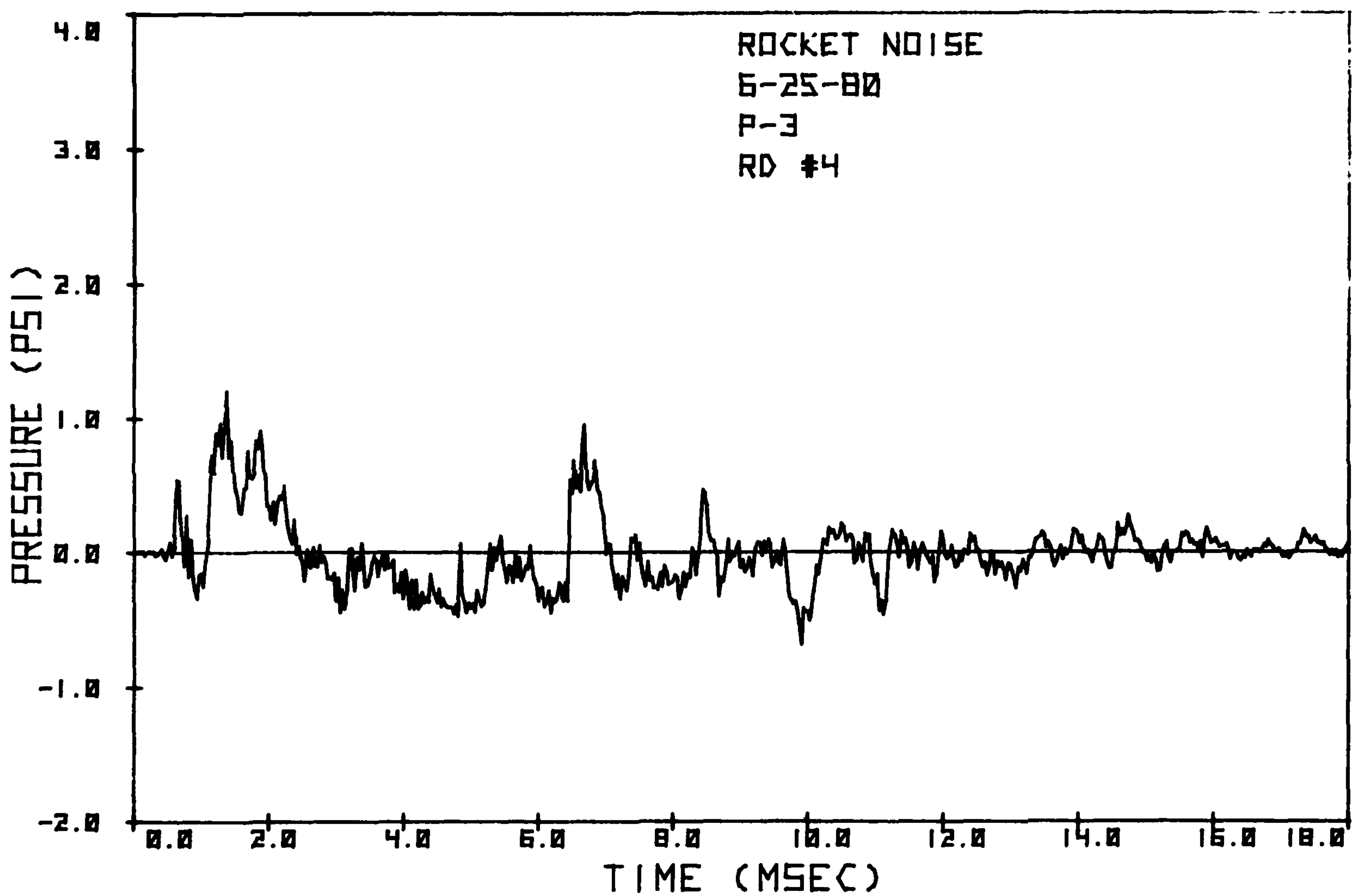
APPENDIX C

TYPICAL RAW NOISE DATA TRACES



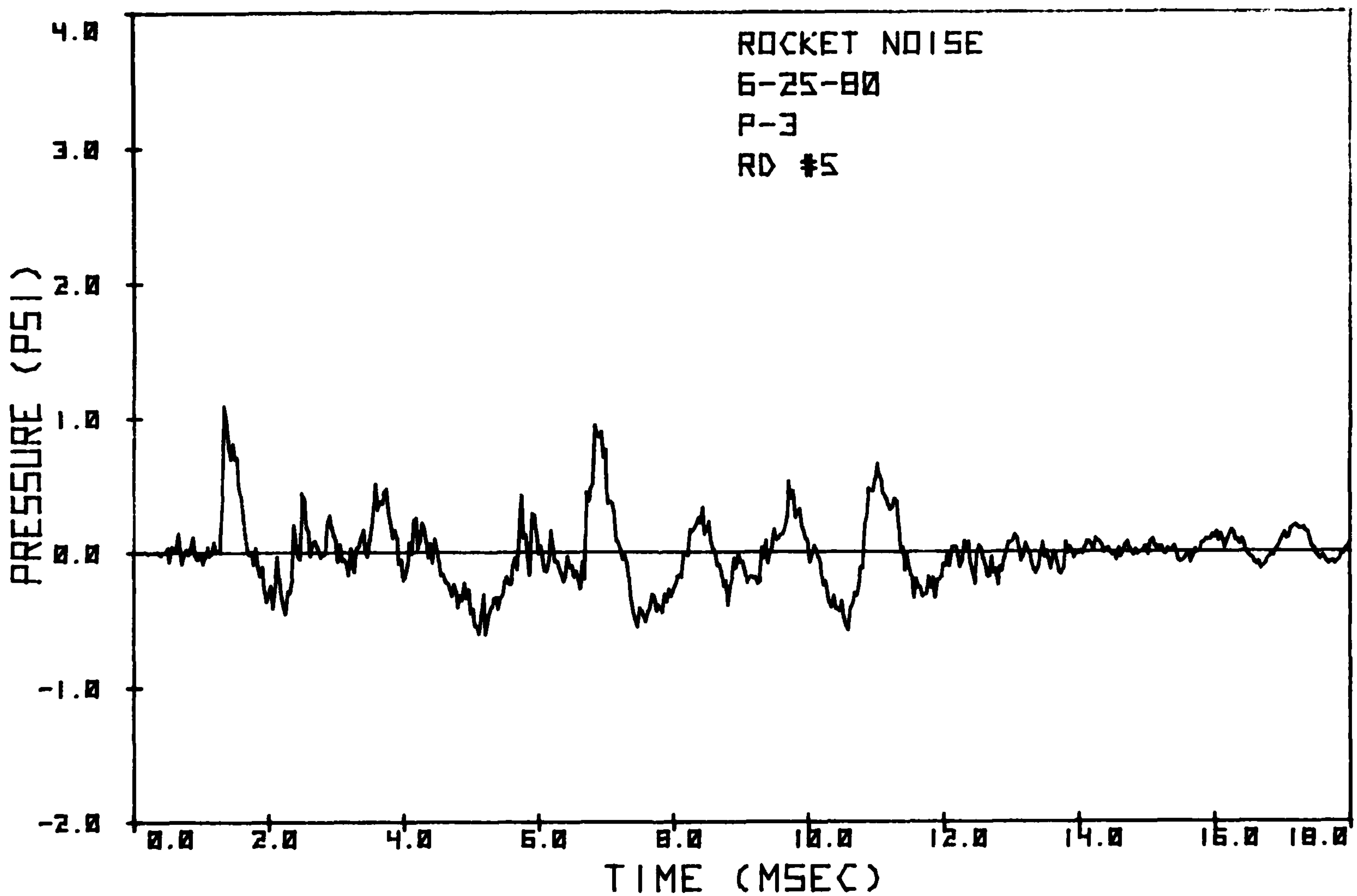
C-1(a). Bare Breech

Figure C-1. Typical Sound Pressure Data for Gunner's Head Location



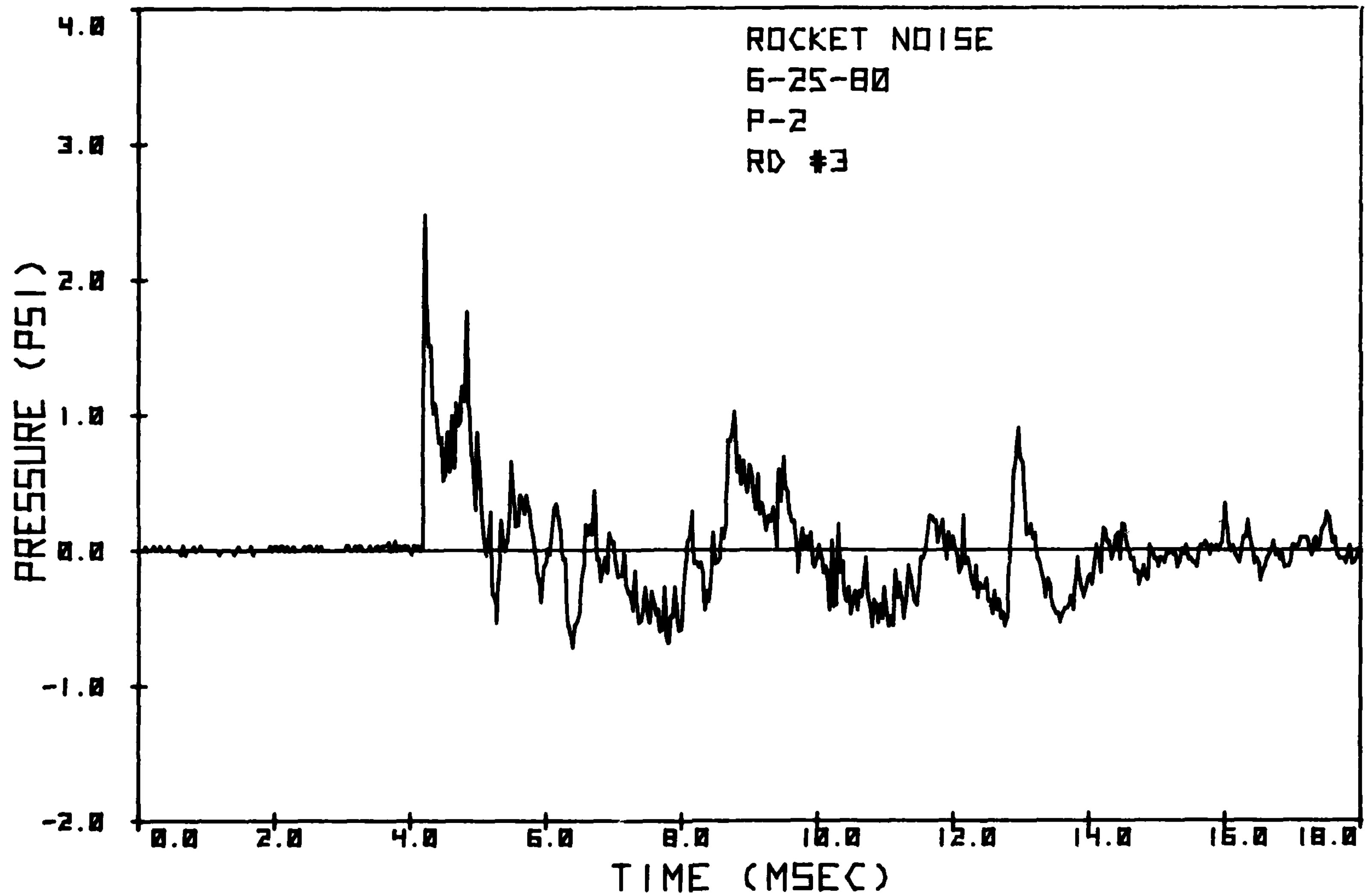
C-1(b). Canister, Empty

Figure C-1. Typical Sound Pressure Data for Gunner's Head Location (Continued)



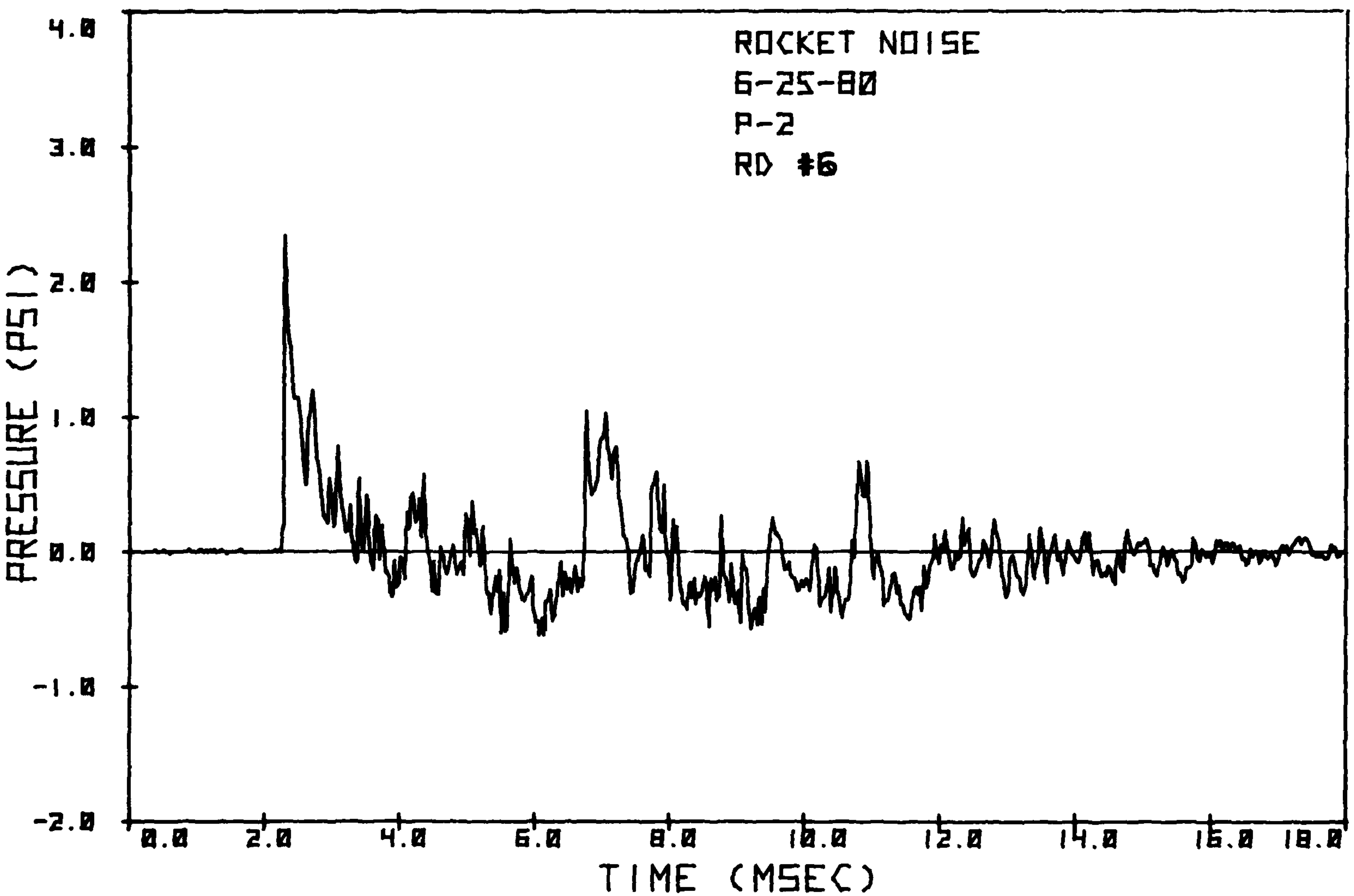
C-1(c). Canister, Foam-Filled

Figure C-1. Typical Sound Pressure Data for Gunner's Head Location (Continued)



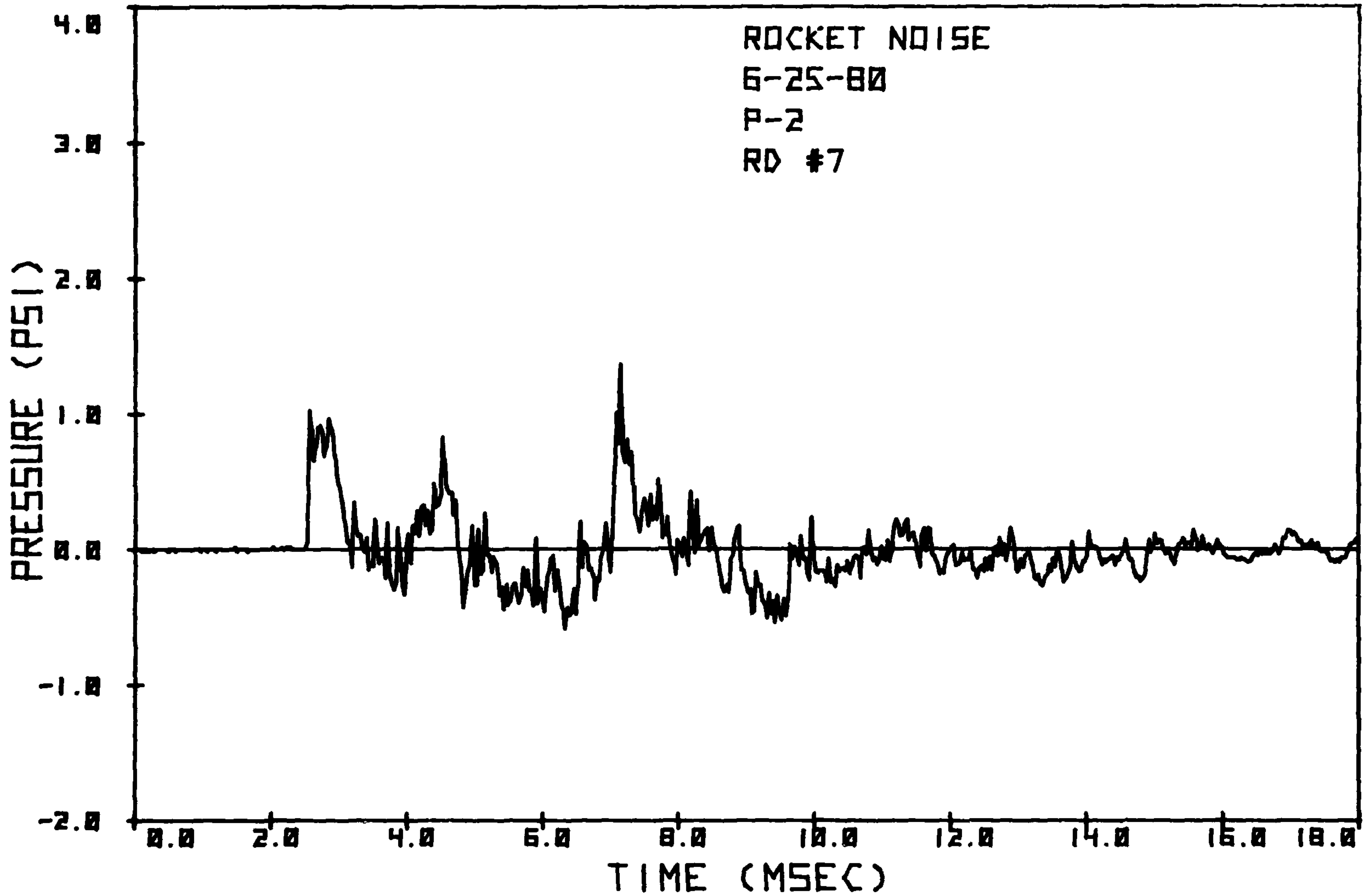
C-2(a). Bare Breech

Figure C-2. Typical Sound Pressure Data at 90°, ≈ 1 Meter from Breech



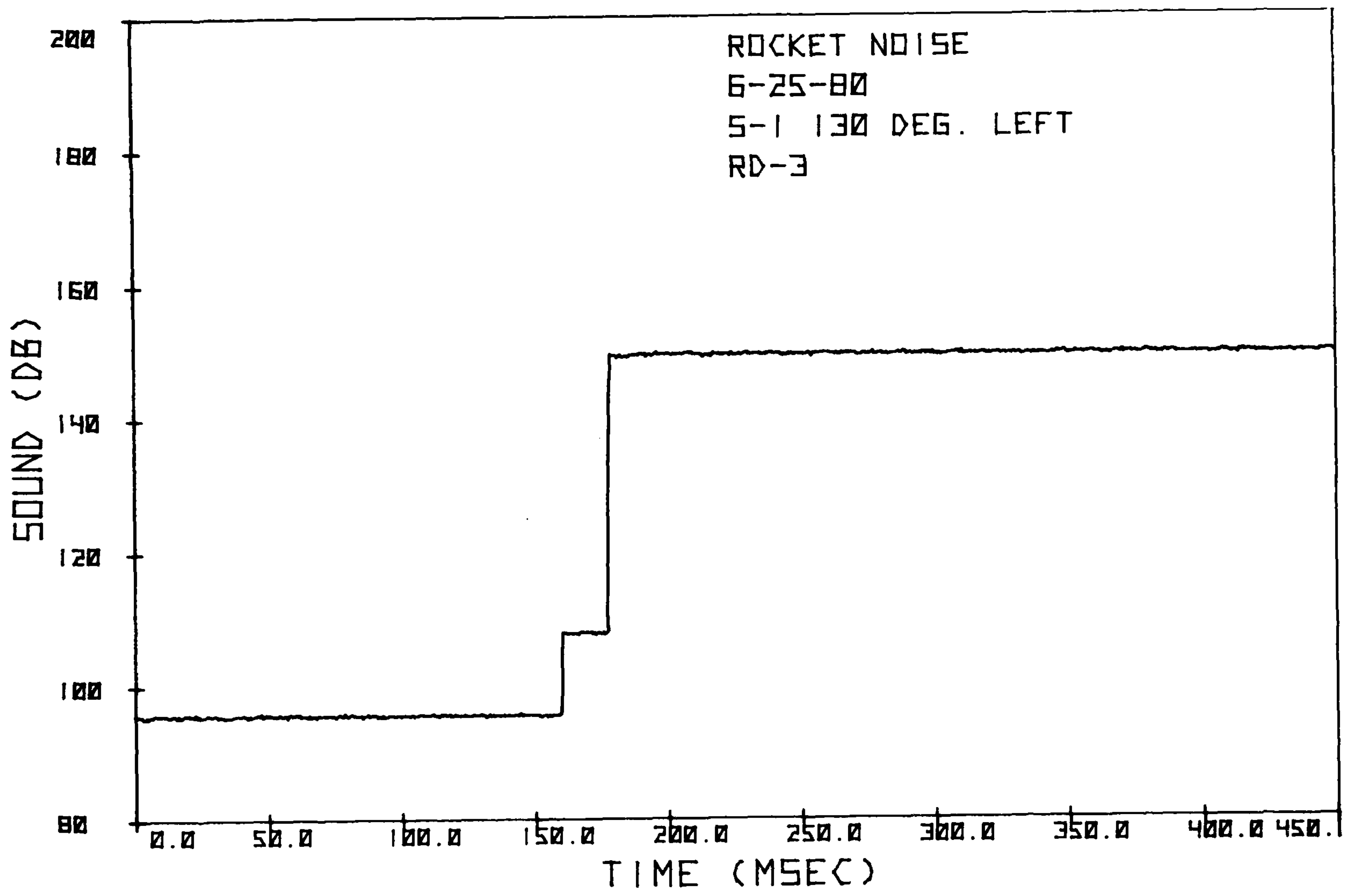
C-2(b). Canister, Empty

Figure C-2. Typical Sound Pressure Data at 90°, ≈ 1 Meter from Breech (Continued)



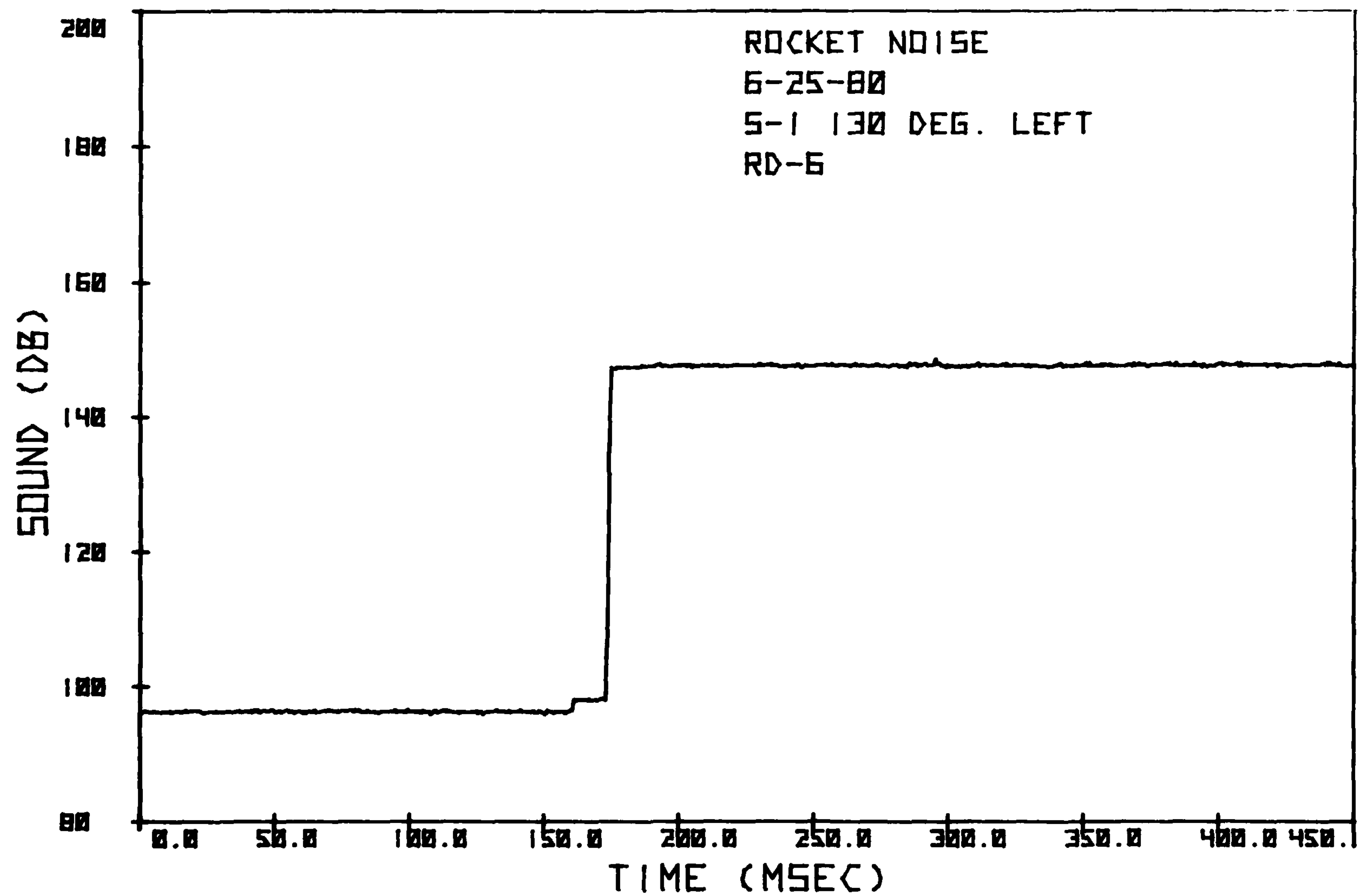
C-2(c). Canister, Foam-Filled

Figure C-2. Typical Sound Pressure Data at 90°, ≈ 1 Meter from Breech (Continued)



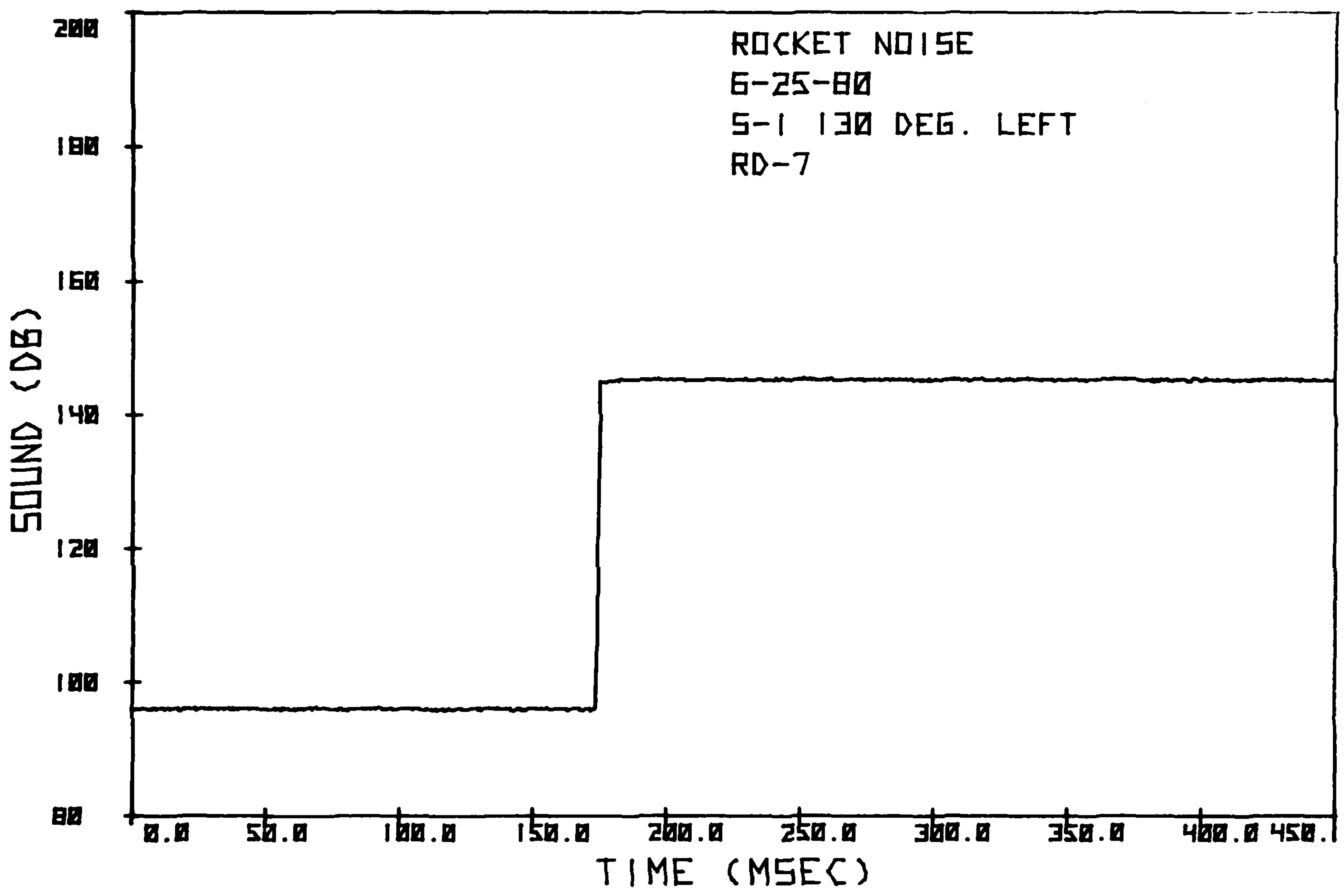
C-3(a). Bare Breech

Figure C-3. Typical Peak-and-Hold Sound Pressure Level Data in the Far Field



C-3(b). Canister, Empty

Figure C-3. Typical Peak-and Hold Sound Pressure Level Data in the Far Field (Continued)



C-3(c). Canister, Foam-Filled

Figure C-3. Typical Peak-and-Hold Sound Pressure Level Data in the Far Field (Continued)

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